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Charles

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(54) **INFUSION PRESSURE CONTROL USING BLOOD PRESSURE**

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(51) **Int. Cl.**

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A61M 5/172	(2006.01)
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A61M 5/168	(2006.01)

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CPC ***A61M 5/1723*** (2013.01); ***G06F 19/3468*** (2013.01); *A61M 5/16854* (2013.01); *A61M 2205/3344* (2013.01); *A61M 2205/3561* (2013.01); *A61M 2210/0612* (2013.01)

(58) **Field of Classification Search**
CPC A61M 1/0058; A61M 2205/60; A61M 2205/6063; A61M 2005/1726; A61M 5/1723
USPC 604/66, 294, 289
See application file for complete search history.

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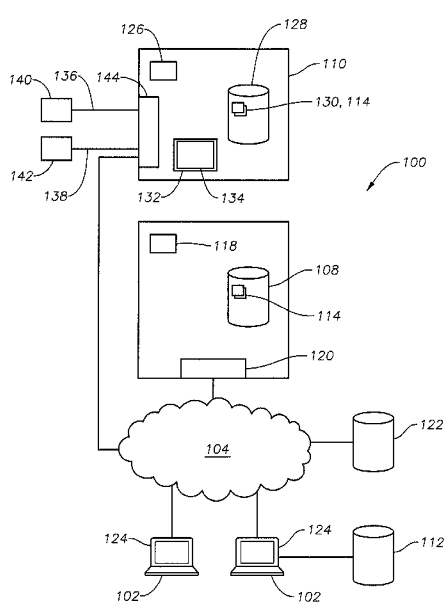
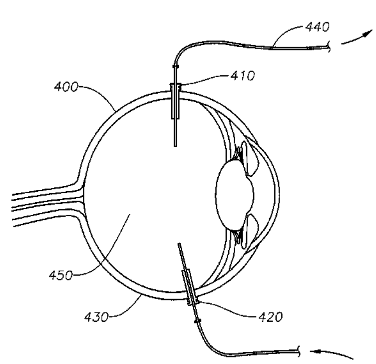
(57) **ABSTRACT**

Methods, systems, and software for controlling infusion pressure, such as during a medical procedure, using systemic blood pressure are described. Systemic blood pressure, such as brachial arm blood pressure or radial artery blood pressure, may be used to estimate central retinal artery blood pressure to estimate critical closing pressure. Further, the disclosure relates to controlling infusion pressure to prevent an increase in intraocular pressure above the estimated critical closing pressure when such is not desired, and, when such is desired, using systemic blood pressure and infusion pressure to control an intentional increase in intraocular pressure above the estimated critical closing pressure to stop intraocular bleeding.

12 Claims, 5 Drawing Sheets





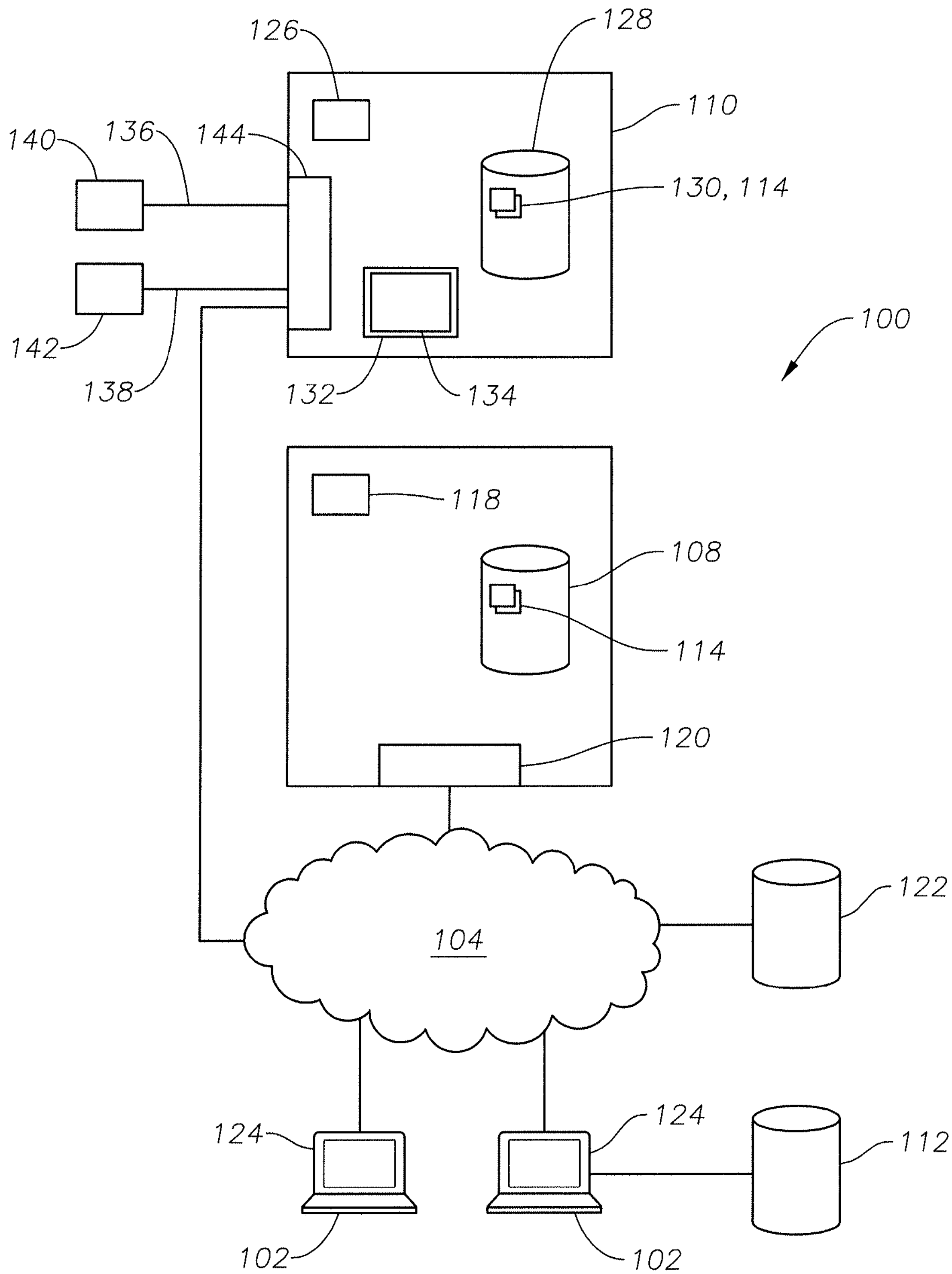

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Fig. 1

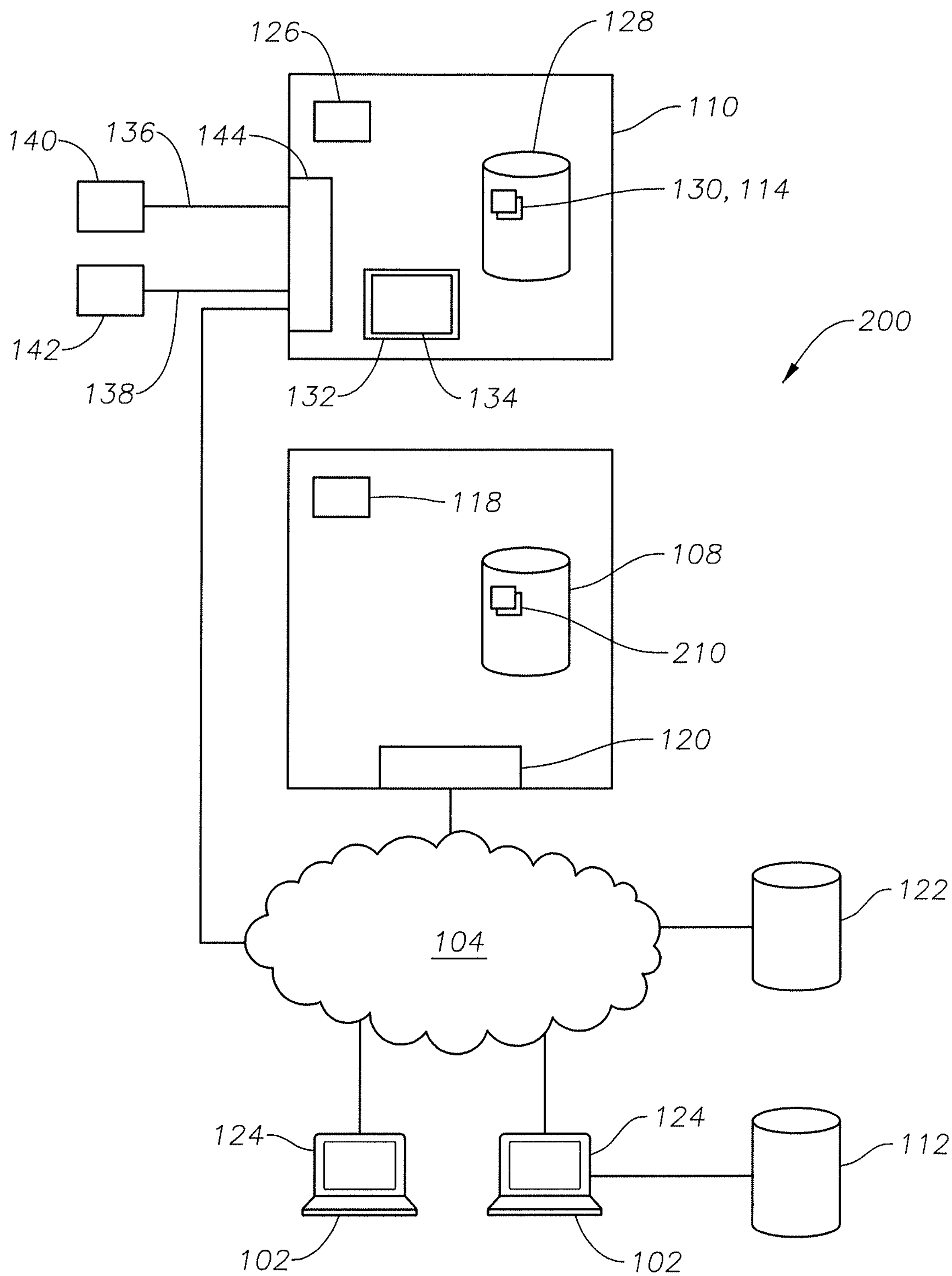
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Fig. 2

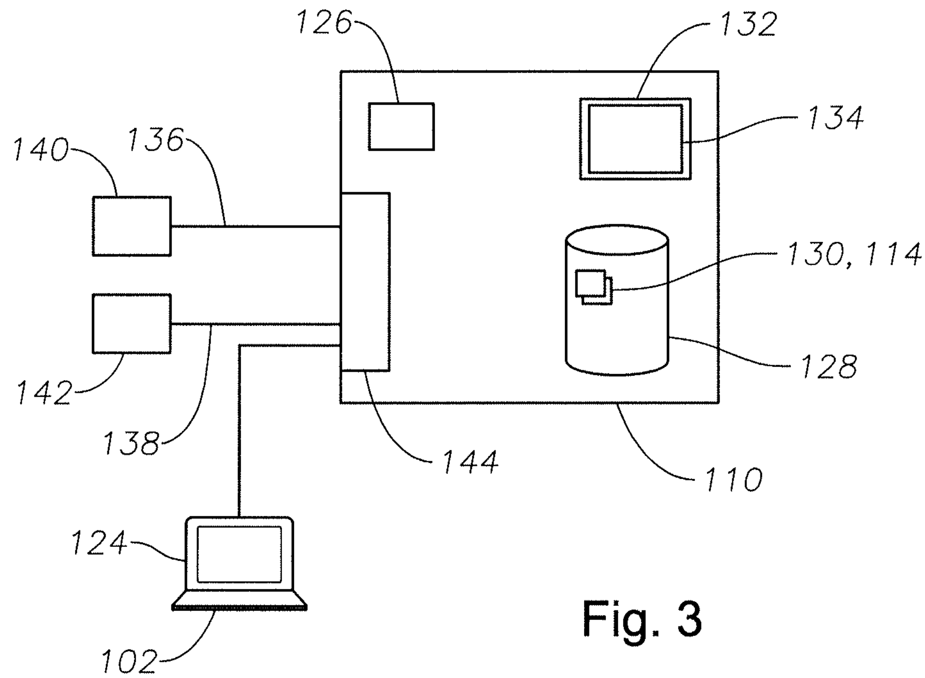
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Fig. 3

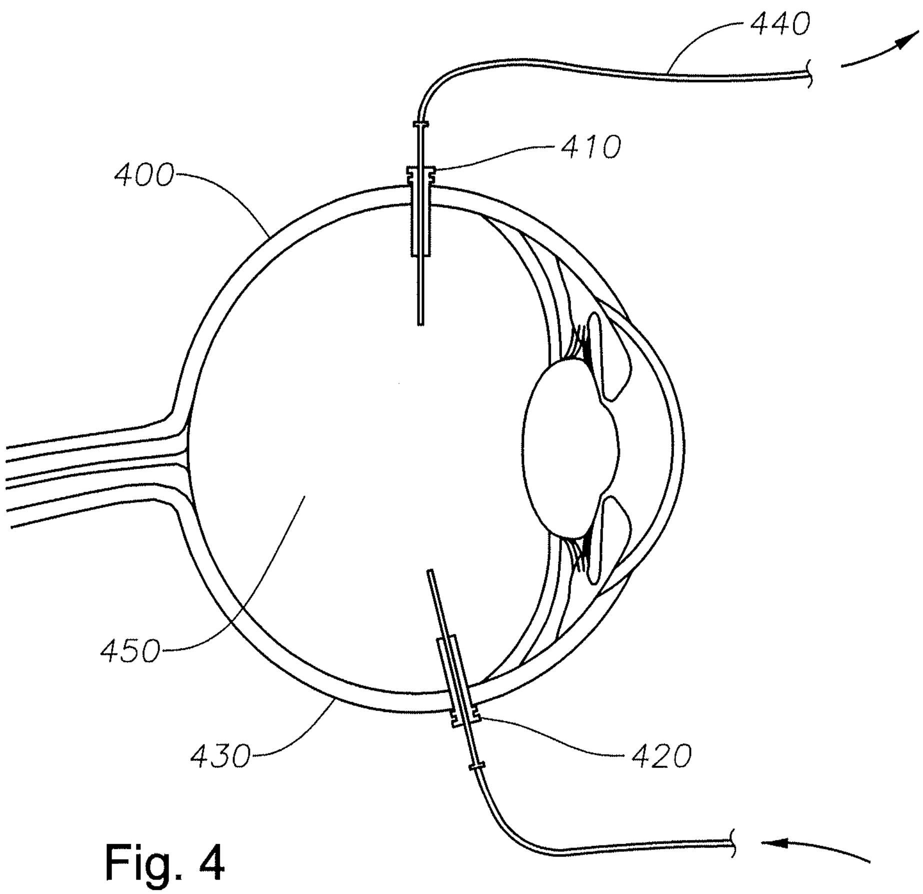
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Fig. 4

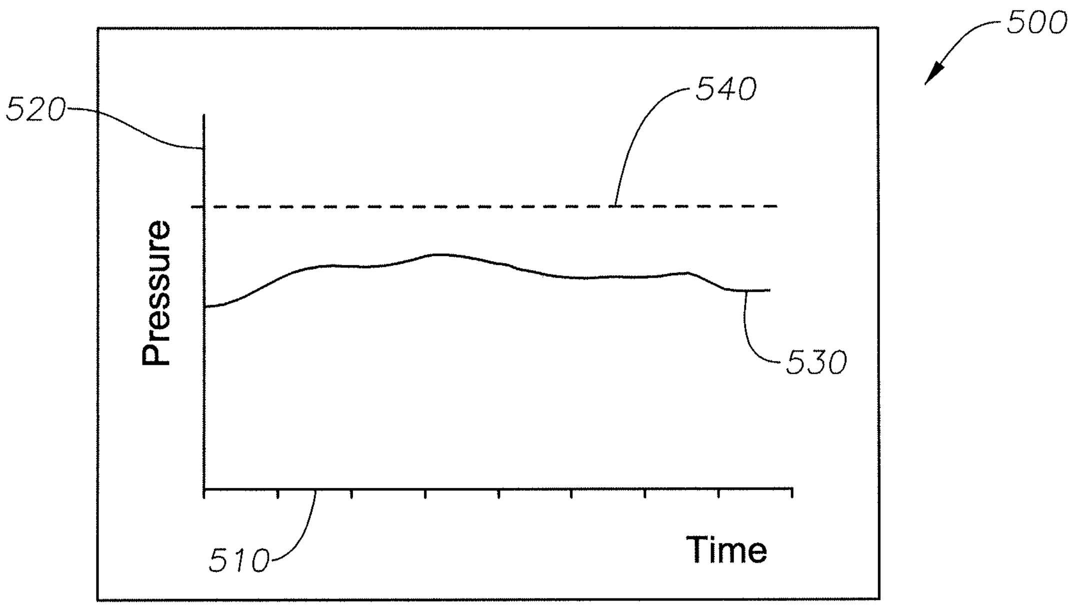
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Fig. 5

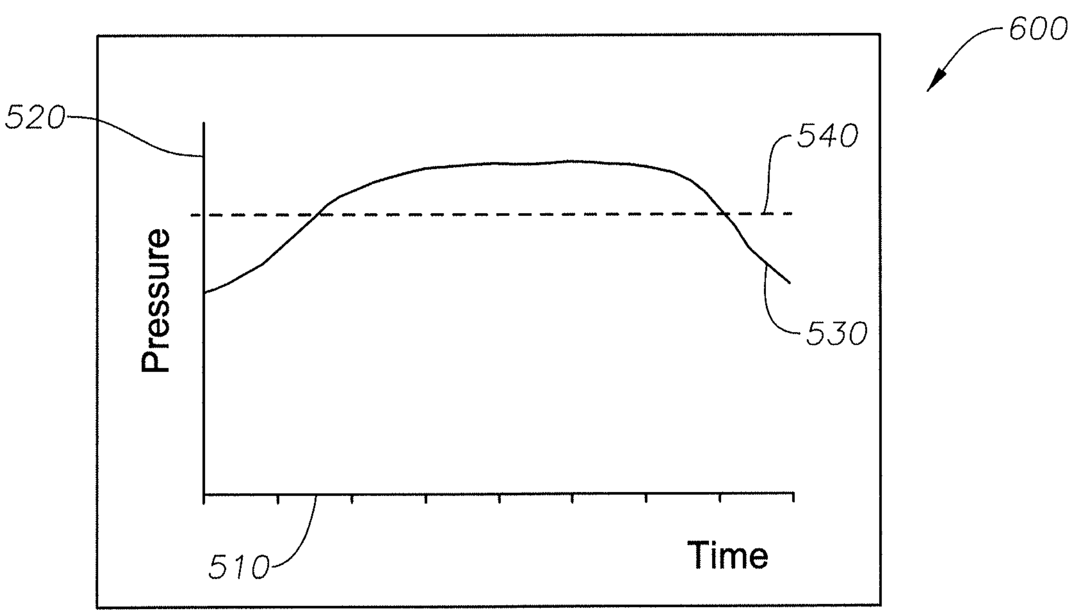
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Fig. 6

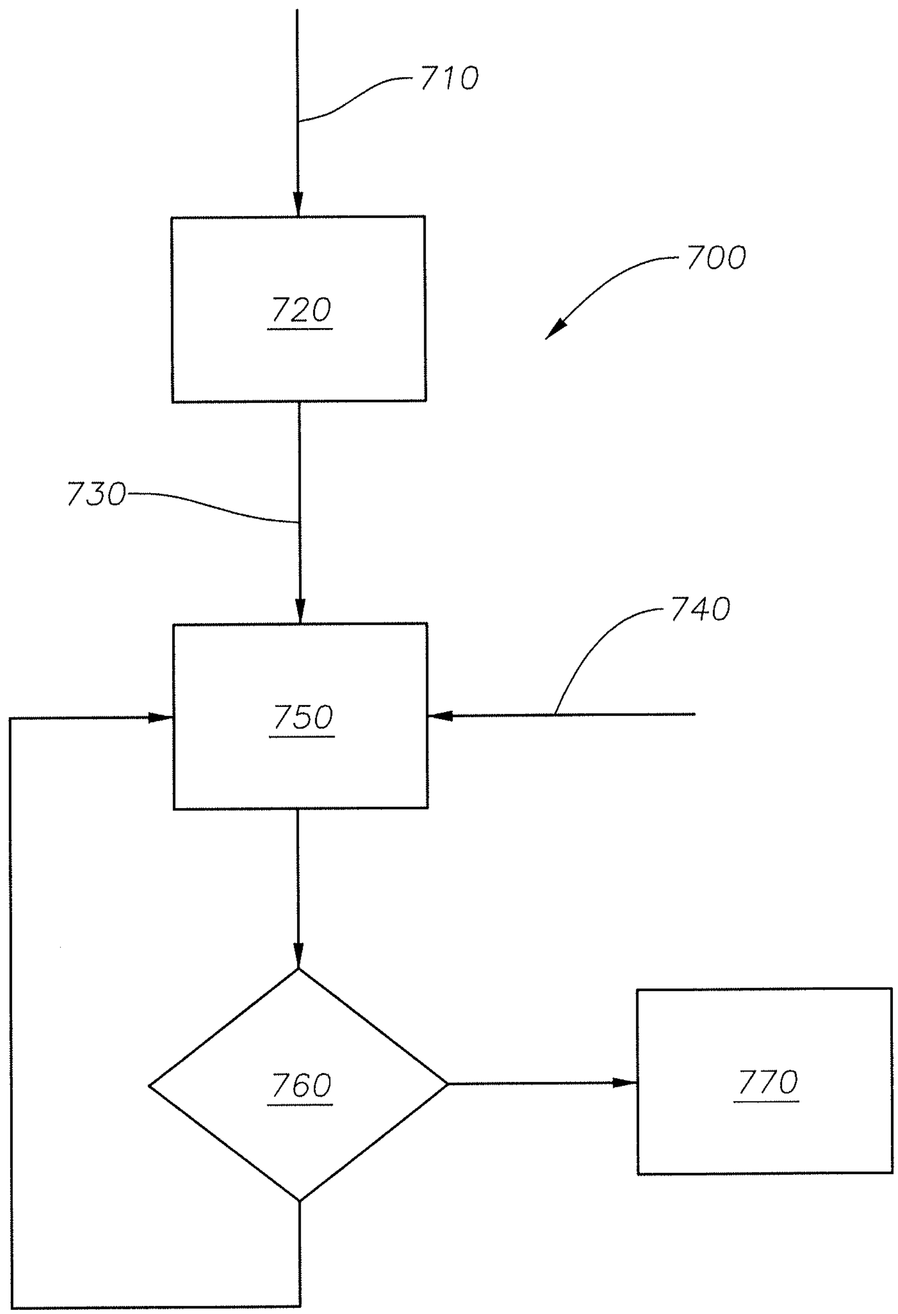

Fig. 7

INFUSION PRESSURE CONTROL USING BLOOD PRESSURE

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a divisional application of prior application Ser. No. 13/112,504, filed May 20, 2011, which claims the benefit of U.S. Provisional Application No. 61/346,746 filed May 20, 2010, the contents of both being incorporated herein by reference.

TECHNICAL FIELD

The present disclosure relates to controlling fluid infusion pressure, such as during an intraocular surgical procedure, utilizing systemic blood pressure. Particularly, the present disclosure describes systems and methods for controlling, and in some instances preventing interruption of, blood flow through the central retinal artery using both systemic blood pressure and fluid infusion pressure.

BACKGROUND

Low systemic blood pressure may be routine when operating on children and often occurs with adults undergoing general anesthesia or deep sedation. Intraocular pressure levels produced by an infusion system, such as during vitreoretinal surgery, may result in occlusion of the central retinal artery if the blood pressure is low. Prolonged vascular occlusion can result in blindness. Such procedures may involve a vitreous hemorrhage, a dense cataract, or some other obstruction that may prevent a medical practitioner from being able to observe circulation in the retinal vessels. Therefore, the retinal vessels are not visible and cannot be monitored for effective blood flow.

SUMMARY

According to one aspect, the disclosure describes a method for controlling infusion pressure, such as during an intraocular surgical procedure. The method may include determining an infusion pressure of a patient's eye with a first pressure determining device, determining a blood pressure indicative of a patient's central retinal artery blood pressure with a second pressure determining device, and determining, with a processor, an estimated critical closing pressure of the central retinal artery of the eye based on the systemic blood pressure.

Another aspect encompasses a computer program product for controlling an infusion pressure. The computer program product may include machine-readable instructions embodied on tangible media and operable when executed to read an infusion pressure of a patient's eye, determine an estimate of a patient's central retinal artery blood pressure, and determine an estimated critical closing pressure of the central retinal artery of the eye based on the estimated central retinal artery blood pressure.

A further aspect relates to a system for controlling infusion pressure during an intraocular surgical procedure. The system may include a data receival unit adapted to receive systemic blood pressure and infusion pressure. The system may also include a computational unit adapted to determine an estimated retinal artery blood pressure based on the received systemic blood pressure and determine an estimated critical closing pressure based on the estimated retinal artery blood pressure. The system may additionally include a logic unit adapted to compare infusion pressure with the estimated critical closure pressure and trigger an alarm when the infusion pressure reaches a selected pressure relative to the estimated critical closing pressure.

Another aspect relates to a computer-implemented method for controlling infusion pressure performed by a processor. The method may include determining an infusion pressure of a patient's eye, determining an estimate of a patient's central retinal artery blood pressure, and determining an estimated critical closing pressure of a central retinal artery of the eye based on the estimated central retinal artery blood pressure.

Another aspect relates to a system including memory for storing at least one of systemic blood pressure data, estimated central retinal artery blood pressure data, infusion pressure data, and estimated critical closing pressure data and one or more processors. The one or more processors may be operable to determine an infusion pressure of a patient's eye, determine an estimate of a patient's central retinal artery blood pressure, and determine an estimated critical closing pressure of a central retinal artery of the eye based on the estimated central retinal artery blood pressure.

The various aspects may include one or more of the following features. A blood pressure indicative of a patient's central retinal artery blood pressure may be determined by determining a patient's systemic blood pressure with a pressure determining device and converting the systemic blood pressure into the estimated central retinal artery blood pressure with a processor. Determining the patient's systemic blood pressure may include determining at least one of the patient's brachial artery blood pressure or radial artery blood pressure with a pressure determining device. The systemic blood pressure may be converted into the estimated central retinal artery blood pressure with an ophthalmodynamometry offset with a processor. The infusion pressure may be compared to the estimated critical closing pressure with a processor. An alarm may be triggered when the infusion pressure reaches a selected pressure relative to the estimated critical closing pressure. An alarm may be at least one of a visual or audible alarm. A patient's systemic blood pressure may be at least one of the patient's brachial artery blood pressure or radial artery blood pressure. Infusion pressure may be increased above the estimated critical closing pressure with a fluid flow device to stop intraocular bleeding. The infusion pressure may be increased above the estimated critical closing pressure for a selected period of time to stop intraocular bleeding at a site of the eye. A procedure may be performed at the site of the eye to prevent continued bleeding after lowering of the infusion pressure below the estimated critical closing pressure. Infusion pressure may be automatically adjusted when the infusion pressure is at a selected value relative to the estimated critical closing pressure. For example, infusion pressure may be reduced when the infusion pressure is equal to or greater than the estimated critical closing pressure.

The various aspects may also include one or more of the following features. Machine-readable instructions operable when executed to read a patient's systemic blood pressure may include machine-readable instructions operable when executed to read at least one of the patient's brachial artery blood pressure or radial artery blood pressure. Machine-readable instructions operable when executed to determine an estimate of a patient's central retinal artery blood pressure may include machine-readable instructions operable when executed to read a patient's systemic blood pressure and convert the systemic blood pressure into the estimated central retinal artery blood pressure. Machine-readable instructions operable when executed to convert the systemic blood pressure into the estimated central retinal artery blood pressure may include machine-readable instructions operable when executed to convert the systemic blood pressure into the estimated central retinal artery blood pressure with an ophthalmodynamometry offset. Machine-readable instructions may also be included that, when executed, trigger an alarm when the infusion pressure reaches a selected pressure relative to the estimated critical closing pressure. The machine-readable instructions operable when executed to trigger an alarm when the infusion pressure reaches a selected pressure relative to the estimated critical closing pressure may include machine-readable instructions operable when executed to trigger at least one of a visual or audible alarm. The machine readable instruction may be operable when to automatically adjusted infusion pressure when the infusion pressure is at a selected value relative to the estimated critical closing pressure. For example, infusion pressure may be reduced when the infusion pressure is equal to or greater than the estimated critical closing pressure.

The various aspects may further include one or more of the following features. A data receival unit adapted to receive systemic blood pressure may be adapted to receive at least one of brachial artery blood pressure or radial artery blood pressure. A computational unit adapted to determine an estimated retinal artery blood pressure based on the received systemic blood pressure may be adapted to convert the systemic blood pressure into the estimated retinal artery blood pressure using an ophthalmodynamometry offset. A logic unit adapted to trigger an alarm when the infusion pressure reaches a selected pressure relative to the estimated critical closing pressure may be adapted to trigger at least one of a visual or audible alarm.

The various aspects may also include one or more of the following features. An estimate of a patient's central retinal artery blood pressure may be determined by determining a patient's systemic blood pressure and converting the systemic blood pressure into the estimated central retinal artery blood pressure. The systemic blood pressure may be converted into the estimated central retinal artery blood pressure with an ophthalmodynamometry offset. An alarm may be triggered when the infusion pressure reaches a selected pressure relative to the estimated critical closing pressure. Triggering an alarm when the infusion pressure reaches a selected pressure relative to the estimated critical closing pressure may include triggering at least one of a visual or audible alarm. A patient's systemic blood pressure may be determined by determining at least one of the patient's brachial artery blood pressure or radial artery blood pressure. The infusion pressure may be increased above the estimated critical closing pressure to stop intraocular bleeding. Increasing the infusion pressure above the estimated critical closing pressure to stop intraocular bleeding may include increasing the infusion pressure above the estimated critical closing pressure for a selected period of time to stop intraocular bleeding at a site of the eye and performing a procedure, during application of the increased infusion pressure, at the site of the eye to prevent continued bleeding after lowering of the infusion pressure below the estimated critical closing pressure. Infusion pressure may be automatically adjusted when the infusion pressure is at a selected value relative to the estimated critical closing pressure. For example, the infusion pressure may be reduced when the infusion pressure is equal to or greater than the estimated critical closing pressure.

The various aspects may include one or more of the following features. One or more processors operable to determine an estimate of a patient's central retinal artery blood pressure may include one or more processors operable to receive a patient's systemic blood pressure and convert the systemic blood pressure into the estimated central retinal artery blood pressure. One or more processors operable to convert the systemic blood pressure into the estimated central retinal artery blood pressure may include one or more processors operable to convert the systemic blood pressure into the estimated central retinal artery blood pressure with an ophthalmodynamometry offset. The one or more processors may be further operable to trigger an alarm when the infusion pressure reaches a selected pressure relative to the estimated critical closing pressure. The triggered alarm may be at least one of a visual or audible alarm. One or more processors operable to receive a patient's systemic blood pressure may include one or more processors operable to receive at least one of the patient's brachial artery blood pressure or radial artery blood pressure. One or more processors may be further operable to automatically adjust infusion pressure when the infusion pressure is at a selected value relative to the estimated critical closing pressure. the one or more processors is further operable to automatically adjust infusion pressure when the infusion pressure is at a selected value relative to the estimated critical closing pressure comprises one or more processors operable to automatically reduce infusion pressure when the infusion pressure is equal to or greater than the estimated critical closing pressure.

The details of one or more implementations of the present disclosure are set forth in the accompanying drawings and the description below. Other features, objects, and advantages will be apparent from the description and drawings, and from the claims.

DESCRIPTION OF DRAWINGS

FIGS. **1-3** are example systems for controlling fluid infusion pressure into an eye.

FIG. **4** is a cross sectional view of an eye undergoing an intraocular surgical procedure.

FIGS. **5-6** show example outputs of central retinal artery blood pressure and critical closing pressure.

FIG. **7** is an example method for controlling fluid infusion pressure to which an eye is subjected during an intraocular surgical procedure.

DETAILED DISCLOSURE

The present disclosure describes methods, systems, and computer software for controlling fluid infusion pressure (i.e., the pressure at which fluid is infused into an eye during an intraocular surgical procedure) (hereinafter referred to as "infusion pressure") using systemic blood pressure. For example, surgical procedures on an eye may include aspiration of a portion of vitreous humor (interchangeably referred to as "vitreous material") from the posterior segment as well as infusion of a fluid into the eye, such as artificial aqueous humor or other fluid (collectively referred to as "infusion fluid"). Aspirating vitreous humor from and infusing infusion fluid into the eye may cause a change in the intraocular pressure ("IOP"). IOP may be particularly affected by the infusion pressure. For example, infusion pressure may be representative of IOP when little or no aspiration from the eye is occurring. However, infusion pressure may be used as an adequate representative of IOP under other conditions during intraocular surgical procedures. The present disclosure describes methods and systems for controlling infusion pressure and, thereby, controlling IOP, during medical procedures as well as providing notification to a medical services provider that infusion pressure has reached a selected pressure.

In an example implementation, an infusion pressure application for controlling infusion pressure ("infusion services") is described. In some instances, the infusion pressure application may be implemented via a system (interchangeably referred to as an "ocular system") that is at least partially electronically implemented. For example, the ocular system may be incorporated into one or more devices. In some instances, the ocular system may form part of a medical apparatus, such as an intraocular medical apparatus. Further, the ocular system may be at least partially implemented over a computer network to one or more remote devices. The present disclosure also describes computer networks that may be utilized for implementing the infusion services in some implementations.

FIG. **1** illustrates an example system **100** for dynamically implementing the infusion services. System **100** may encompass an example ocular system that may be operable to transmit information to one or more clients **102**, receive information from one or more of the clients **102**, and otherwise administer and control various aspects of the infusion services.

System **100** may be a distributed client/server system that spans one or more networks, such as network **104**. In such implementations, data may be communicated or stored in an encrypted format using any standard or proprietary encryption algorithm. In other instances, the data may be stored at least partially in an unencrypted format. System **100** may be in a dedicated environment, implemented across a local area network or subnet, or implemented in any other suitable environment without departing from the scope of this disclosure. In some instances, the system **100** may include or be communicably coupled with a server **106**, one or more clients **102**, network **104**, and one or more medical devices **110**. Additionally, one or more of the clients **102** may be communicably coupled to a repository **112**. In some implementations, the one or more clients **102** may be consoles utilized by medical practitioners to control the infusion services, either alone or in addition to other aspects associated with the system **100**. Further, system **100** may include additional or different features and components than those described.

Server **106** may include an electronic computing device operable to receive, transmit, process, and store data associated with system **100**. Generally, FIG. **1** provides merely one example of computers that may be used with the disclosure. Each computer is generally intended to encompass any suitable processing device. For example, although FIG. **1** illustrates one server **106** that may be used with the disclosure, system **100** can be implemented using computers other than servers, as well as a server pool. Indeed, server **106** may be any computer or processing device such as, for example, a blade server, general-purpose personal computer (PC), Macintosh, workstation, Unix-based computer, or any other suitable device. In other words, the present disclosure contemplates computers other than general purpose computers as well as computers without conventional operating systems. Server **106** may be adapted to execute any operating system including Linux, UNIX, Windows Server, or any other suitable operating system. According to one embodiment, server **106** may also include or be communicably coupled with a web server and/or a mail server.

The server **106** may include local memory **108**. Memory **108** may include any memory or database module and may take the form of volatile or non-volatile memory including, without limitation, magnetic media, optical media, random access memory (RAM), read-only memory (ROM), removable media, or any other suitable local or remote memory component. Illustrated memory **108** may include, among other items, an infusion pressure application **114**. For example, medical practitioners may use the clients **102** to interact with activities associated with operation of the medical device **110**, including the infusion services at least partially provided by the infusion pressure application **114**. For example, in some instances, the infusion services may be conducted entirely on the server **102** with information sent to and from each client **104** and/or medical device **110** to interact with the infusion pressure application **114**.

In other instances, infusion services of the infusion pressure application **114** may be performed partially on the server **106** and partially at one or more locations remote from the server **106**. For example, in some implementations, the infusion services of the infusion pressure application **114** may be partially or fully performed on the medical device **110**.

Memory **108** may store classes, frameworks, applications, backup data, jobs, or other information that includes any parameters, variables, algorithms, instructions, rules, or references thereto. Memory **108** may also include other types of data, such as environment and/or application description data, application data for one or more applications, as well as data involving virtual private network (VPN) applications or services, firewall policies, a security or access log, print or other reporting files, HyperText Markup Language (HTML) files or templates, related or unrelated software applications or subsystems, and others. Consequently, memory **108** may also be considered a repository of data, such as a local data repository from one or more applications. Memory **108** may also include data that can be utilized by the infusion pressure application **114**.

Server **106** may also include processor **118**. Processor **118** executes instructions and manipulates data to perform the operations of the server **106**, e.g., computational and logic operations, and may be, for example, a central processing unit (CPU), a blade, an application specific integrated circuit (ASIC), or a field-programmable gate array (FPGA). Although FIG. **1** illustrates a single processor **118** in server **106**, multiple processors **118** may be used according to particular needs and reference to processor **118** is meant to include multiple processors **118** where applicable. In the illustrated embodiment, processor **118** executes infusion pressure application **114**.

Server **106** may also include interface **120** for communicating with other computer systems, such as clients **102**, over network **104** in a client-server or other distributed environment. For example, the interface **120** may receive data from different parts of the system **100** or from sources outside of the system **100** as well as transmit data to different parts of the system **100** or to locations outside of the system **100**. In certain embodiments, server **106** receives data from internal or external senders through interface **120** for storage in memory **108** and/or processing by processor **118**. Generally, interface **120** comprises logic encoded in software and/or hardware in a suitable combination and operable to communicate with network **104**. More specifically, interface **120** may comprise software supporting one or more communications protocols associated with communications network **104** or hardware operable to communicate physical signals.

Network **104** facilitates wireless or wireline communication between computer server **106** and any other local or remote computer, such as clients **102**. Network **104** may be all or a portion of an enterprise or secured network. In another example, network **104** may be a VPN merely between server **106** and client **102** across wireline or wireless link. Such an example wireless link may be via 802.11a, 802.11b, 802.11g, 802.20, WiMax, and many others. While illustrated as a single or continuous network, network **104** may be logically divided into various sub-nets or virtual networks without departing from the scope of this disclosure, so long as at least a portion of network **104** may facilitate communications among server **106**, at least one client **102**, and other device, such as medical device **110**, discussed in more detail below. For example, server **106** may be communicably coupled to a repository **122** through one sub-net while communicably coupled to a particular client **102** through another. In other words, network **104** encompasses any internal or external network, networks, sub-network, or combination thereof operable to facilitate communications between various computing components in system **100**. Network **104** may communicate, for example, Internet Protocol (IP) packets, Frame Relay frames, Asynchronous Transfer Mode (ATM) cells, voice, video, data, and other suitable information between network addresses (collectively or interchangeably referred to as "information"). Network **112** may include one or more local area networks (LANs), radio access networks (RANs), metropolitan area networks (MANs), wide area networks (WANs), all or a portion of the global computer network known as the Internet, and/or any other communication system or systems at one or more locations. In certain embodiments, network **104** may be a secure network accessible to users via certain local or remote clients **102**.

Client **102** may be any computing device operable to connect or communicate with server **106** or network **104** using any communication link. At a high level, each client **102** includes or executes at least graphical user interface ("GUI") or application interface (collectively referred to as "GUI **124**") and comprises an electronic computing device operable to receive, transmit, process, and store any appropriate data associated with system **100**. It will be understood that there may be any number of clients **102** communicably coupled to server **104**. Further, "client **102**" and "user" may be used interchangeably as appropriate without departing from the scope of this disclosure. Moreover, for ease of illustration, each client **104** is described in terms of being used by one user. But this disclosure contemplates that many users may use one computer or that one user may use multiple computers. As used in this disclosure, client **102** is intended to encompass a personal computer, touch screen terminal, workstation, network computer, kiosk, wireless data port, smart phone, personal data assistant (PDA), one or more processors within these or other devices, or any other suitable processing device. For example, client **102** may be a PDA operable to wirelessly connect with an external or unsecured network. In another example, client **102** may comprise a laptop computer that includes an input device, such as a keypad, touch screen, mouse, or other device that can accept information, and an output device that conveys information associated with the operation of server **106** or clients **102**, including digital data, visual information, or user interface, such as GUI **124**. Both input devices and output devices may include fixed or removable storage media such as a magnetic computer disk, CD-ROM, or other suitable media to both receive input from and provide output to users of clients **102** through, for example, a display. In some instances, the display may include the client portion of GUIs **124**.

GUI **124** may include a graphical user interface operable to allow the user of client **102** to interface with at least a portion of system **100** for any suitable purpose, such as viewing application or other transaction information. For example, GUI **124** could provide information associated with a medical procedure, including detailed information related to infusion pressure and/or other information related to the infusion pressure application **114**. Generally, GUI **124** may provide a particular user with an efficient and user-friendly presentation of information provided by or communicated within system **100**. GUI **124** may include a plurality of customizable frames or views having interactive fields, pull-down lists, and buttons operated by the user. GUI **124** may also present a plurality of portals or dashboards. For example, GUI **124** may display a secure webpage that allows users to input and define parameters associated with the infusion services. It should be understood that the term graphical user interface may be used in the singular or in the plural to describe one or more graphical user interfaces and each of the displays of a particular graphical user interface. Indeed, reference to GUI **124** may indicate a reference to the front-end or a component of infusion pressure application **114**, as well as the particular interface accessible via client **102**, as appropriate, without departing from the scope of this disclosure. Therefore, GUI **124** contemplates any graphical user interface. For example, in some instances, the GUI **124** may include a generic web browser or touch screen that processes information in system **100** and efficiently presents the results to the user. In other instances, the GUI **124** may include a custom or customizable interface for displaying and/or interacting with the various features of the infusion pressure application **114** or other infusion services. Further, in some instances, server **106** may accept data from client **102** and return the appropriate HTML or XML responses to the browser using network **104**. In some instances, information between the server and the client **102** may be transmitted via a web browser (e.g., Microsoft Internet Explorer or Netscape Navigator) or other application. In some instances, software utilized for transmitted information may be integrated within the infusion pressure application **114**.

The medical device **110** may include a processor **126**, similar to processor **118**, memory **128**, similar to memory **108**, and one or more applications **130**. For example, the one or more applications **130** may include infusion pressure application **114** or a portion thereof. Further, the medical device **110** may be adapted to execute any suitable operating system. The medical device **110** may also include a display **132** for displaying information to a user, such as a medical practitioner. Further, the display **132** may present the present information to the user via a GUI **134**, which may be similar to the GUI **124**, described above. The medical device **110** may send and receive information to and from the server **106** as well as to and from clients **102** via the network **104**. Aspects of operation of the medical device **110** may be monitored and/or controlled from the medical device **110**, the server **106**, and/or the client **102**. For example, one or more aspects or services of operation of the medical device **110** may be performed and/or altered by the medical device **110**, by the server **106**, and/or by a user via client **124**.

The medical device **110** may also include an interface **144**, similar to interface **120**, for communicating data with components, both within and outside of the system, including computer systems, such as clients **102**, server **106**, or other components, directly or over network **104** in a client-server or other distributed environment. The medical device **110** may receive one or more inputs, such as inputs **136** and **138**. Inputs **136** and **138**, as well as any other desired inputs to the medical device **110**, may be received and/or outputs transmitted via the interface **144**.

In some instances, the inputs **136** and **138** may respectively represent infusion services information, such as measurement data representative of a medical condition or aspect of a patient's health. Inputs **136** and **138** may be communicated to the medical device **110** in any desirable manner. For example, one or more of the inputs **136**, **138** may be transmitted to the medical device **110** over a wireline connection (e.g., via an

Ethernet, USB, IEEE 1394, or other wired connection) or wireless connection (e.g., an 802.11a, 802.11b, 802.11g, 802.20, WiMax, ZigBee, Ultra-Wideband ("UWB"), or any other wireless link).

In some implementations, input **136** may represent systemic blood pressure data, while input **138** may represent data indicative of intraocular pressure, such as infusion pressure data. However, inputs may represent any characteristics of a patient's health, such as heart rate, pulse, respiration rate, etc. Further, inputs **136** and **138** may be provided to the medical device **110** from components **140** and **142**, respectively. Further, in some instances, input **136** and input **138** may be in the form of a digital or analog signal. Components **140** and **142** may be another device, such as another medical device, from which data may be desired. In some instances components **140** and/or **142** may be a sensor coupled directly or indirectly to the patient. Example devices **140** and **142** may be anesthesia devices or sensors, vital sign monitoring devices or sensors, or any other desired device or sensor that may provide information associated with performing a medical procedure on a patient. In some instances, devices **140** and **142** may be adapted to determine one or more of a patience's vital signs, such as blood pressure, pulse rate, etc. For example, device **140** and/or **142** may be adapted to determine blood pressure by sensing blood pressure.

In still other implementations, medical device **110** may incorporate devices and/or sensors **140** and **142**. For example, medical device **110** may include pressure measurement components, temperature measurement components, flow rate measurement components, as well as others. In some instances, the pressure measurement component may include a pressure transducer, or, in other instances, the pressure measurement component may include a combination of devices and/or sensors adapted to measure pressure, such as one or more pressure transducers, one or more flow rate measurement devices, one or more temperature sensors, and/or any other suitable instrument. Further, medical device **110** may include any other or different sensors and devices than those described.

While the above description with respect to FIG. **1** describes the server **106** at least partially executing and/or providing services associated with the infusion pressure application **114**, FIG. **2** illustrates an alternate implementation in which services associated with infusion pressure application **114** may entirely be performed on and/or by the medical device **110**. Further, the medical device **110** may also perform other functions or provide other services.

Accordingly, FIG. **2** shows a system **200** including medical device **110**, server **106**, network **104**, and clients **102**, similar to those described above. The server **106** may include one or more application **210** provided in memory **108**. Also similar to above, the medical device **110** may receive inputs **136** and **138**. Other components may also be included in system **200**. For example, system **200** may include multiple medical devices and/or multiple servers. Communication between the medical device **110** and client **102** may be provided via network **104**.

FIG. **3** shows a still further implementation in which the medical device **110** for performing the services associated with the infusion pressure application **114** is in a stand-alone configuration. The medical device **110** may be similar to that described above. For example, the medical device **110** may include, among other features, processor **126**, memory **128**, display **132**, and receive inputs **136** and **138**. These components may be similar to those components described above. The memory **128** may include infusion pressure application **114**, and processor **126** may execute the instructions of infusion pressure application **114**. Accordingly, the medical device **110** may exclusively provide all services associated with the infusion pressure application **114**. The medical device **110** may also be coupled to a client **102**, through which a user may monitor or make changes to an operating condition of the medical device **110**.

In some implementations, the medical device **110** may be a vitreoretinal surgical system. Example vitreoretinal surgical systems may include, but are not limited to, the Accurus® Surgical System produced by Alcon Laboratories, Inc. of Alcon Laboratories, Inc., 6201 South Freeway, Fort Worth, Tex. 76134 and the Constellation® Vision System also produced by Alcon Laboratories, Inc.

The infusion pressure application **114** may provide one or more of the features described below. FIG. **4** shows a cross-sectional view of an eye **400** undergoing a medical procedure involving, for example, a vitrectomy. A first cannula **410** and a second cannula **420** may be inserted through the sclera **430** and into the posterior segment **40** of the eye **20**. Vitreous material may be evacuated through the cannula **410** and carried away through a tube **440** or other suitable structure. Infusion fluids may be introduced into the posterior segment **450** via the second cannula **420**.

As the vitreous material is removed from and infusion fluid is introduced into the posterior segment **450**, intraocular pressure may fluctuate. For example, if the rate of aspiration of material from the eye is greater than the rate material is infused into the eye, the TOP may drop. On the other hand, if the rate at which material is aspirated from the eye is less than the rate at which material is infused into the eye, the IOP may increase. Generally, infusion pressure may be determined and used as a proxy for IOP. That is, during an intraocular surgical procedure, infusion pressure generally may have the greatest effect on and, therefore, be representative of IOP. A signal corresponding to the infusion pressure may be transmitted to a processor, such as processor **126** or **118**.

The infusion pressure may be carefully controlled. For example, if infusion pressure exceeds a certain threshold, IOP corresponding thereto may exceed the critical closing pressure ("CCP"). Consequently, vascular occlusion may result. During a surgical procedure, IOP may be altered, for example, by adjusting the infusion pressure. In other instances, TOP may be altered by adjusting the rate at which vitreous material is aspirated, the rate at which infusion fluid is infused, or both.

CCP may vary with a patient's blood pressure. For example, for a patient having a low blood pressure or as a patient's blood pressure drops during a medical procedure, the pressure necessary to prevent blood flow through the central retinal artery (i.e., the CCP) will be lower. On the other hand, for a patient with high blood pressure or as the patient's blood pressure increases during a medical procedure, the CCP raises.

In some implementations, during an intraocular surgical procedure, such as one involving a vitrectomy, a patient's systemic blood pressure may be monitored. In some instances, the measured systemic blood pressure may be brachial artery blood pressure. The systemic blood pressure may be monitored and provided as an input to a control or monitoring device. The systemic blood pressure may be measured, for example, by a pressure cuff or other suitable device, and a signal corresponding thereto may be transmitted to a processor, such as the processor that receives the intraocular blood pressure. Alternately, a signal corresponding to the systemic blood pressure may be transmitted to a different processor.

The systemic blood pressure may be converted into an estimated central retinal artery blood pressure (interchangeably referred to as "retinal blood pressure") according to known methods. For example, an offset, such as a conversion factor or algorithm, for converting from systemic blood pressure to retinal blood pressure may be an ophthalmodynamometry derived offset. That is, the offset may be obtained from ophthalmodynamometry studies. A processor may determine the retinal blood pressure using the systemic blood pressure and offset. Accordingly, the processor may determine an estimated critical closing pressure and compare the estimated CCP to the infusion pressure.

In some instances, if the infusion pressure is equal to or above the retinal blood pressure or another selected pressure, the infusion pressure may be automatically adjusted to prevent occlusion from occurring. Alternately or in addition, an alarm may be triggered by the infusion pressure condition. For example, in some instances, a medical device, such as medical device **110**, may receive as inputs infusion pressure and systemic blood pressure, automatically determine an estimated retinal blood pressure from the received systemic blood pressure, determine the estimated critical closure pressure from the retinal blood pressure, and compare the infusion pressure to a selected pressure (e.g., the estimated critical closing pressure or another pressure associated therewith). If the infusion pressure is equal to, above, or at some other level relative to the selected pressure, the medical device may automatically adjust the infusion pressure to keep the infusion pressure at a desired level. Further, the medical device may also trigger an alarm to notify the medical practitioners of the infusion pressure level.

Infusion pressure may be increased or otherwise altered by adjusting a pressure head, such as by altering a pump speed, altering a gas pressure (such as in gas forced infusion or vented gas force infusion), or altering a gravity pressure head. A gravity pressure head may be altered by adjusting a height of a volume of fluid, such as by changing a height of a container of fluid either manually or in an automated fashion. For example, a gravity pressure head may be altered in an automated fashion with an electronically controlled motorized staff that automatically adjusts a height of a fluid container coupled thereto to maintain a desired pressure head. Collectively, mechanisms for accomplishing these pressure heads, such as those described above, may be referred to as "fluid flow devices".

In other implementations, the infusion pressure (and, hence, the IOP) may be intentionally increased above the CCP. For example, the infusion pressure may be intentionally increased above the CCP to stop intraocular bleeding. The infusion pressure may be maintained at the elevated pressure so that intraocular bleeding may be corrected. Once the site at which intraocular bleeding has been corrected and the infusion pressure may be lowered to a level below critical closing pressure, the bleeding is prevented from reoccurring. Example procedures and mechanisms for repairing a bleed site may include coagulation, suturing, and cauterization. Thereafter, infusion pressure may be lowered below the CCP thereby permitting blood flow through the central retinal artery.

One or more of the systemic blood pressure, estimated retinal blood pressure, estimated CCP, or infusion pressure may be displayed to a user, such as a medical practitioner. For example, such output may be displayed on a display, such as display of a client **102** and/or display **132**. The output may be incorporated into a GUI, such as GUI **124** and/or GUI **134**. FIGS. **5-6** show example display outputs for presenting the outputted information to the user. FIG. **5** shows a display output **500** including a pair of axes **510**, **520**. In some instances, the horizontal axis **510** my represent "time", while the vertical axis **520** may indicate "pressure". FIG. **5** shows the behavior over time of infusion pressure **530** relative to estimated CCP **540**. In this instance, the infusion pressure **530** is shown below the estimated CCP **540** for a period of time. FIG. **6** also shows an example display output **600** in which infusion pressure **530** has increased beyond the estimated CCP **540** for a period of time.

FIG. **7** shows an example method **700** for controlling infusion pressure using systemic blood pressure. Systemic blood pressure **710** may be obtained and used as an input at **720**. At **720**, the systemic blood pressure **710** may be converted into retinal blood pressure **730**. For example, the retinal blood pressure **730** may be determined from the systemic blood pressure **710** using an offset obtained from ophthalmodynamometry studies. The determined retinal blood pressure **730** may be defined as the critical closing pressure. At **750**, the critical closing pressure may be compared to infusion pressure **740**. At **760**, if the infusion pressure **740** is greater than and/or equal to the critical closing pressure, an alarm **770** may be triggered. A return to **750** may be made at which time subsequent critical closing pressure and infusion pressure **750** comparisons may be made.

In some instances, the alarm may be a visual alarm. Example visual alarms may include a message displayed on a display, a flashing light, or some other visual indicator. In other instances, the alarm may be an audible alarm. Example audible alarms may include a buzzer, a siren, or some other audible cue to indicate to the user or medical practitioner that an alarm has been triggered. In still other instances, the audible alarm may be in the form of a pre-recorded or computer-generated message. For example the pre-recorded or computer-generated message may be or mimic a human voice that indicates that a pressure is above a predetermined value. The message may also repeat at regular, irregular, or any other desired interval and include recitation of an elapsed time during which the pressure has exceeded the predetermined pressure value. Further, the alarms may have an escalation feature. That is, alarm of one type may be triggered at a first pressure, while a second type of alarm may be triggered at a different pressure. Such a feature may provide for a series of escalating alarms as the measured infusion pressure increases above predetermined intervals.

It is noted that, in some instances, while an alarm may be triggered at **770** based on determinations made at **760** the method may be applied on a continuous basis whether or not an alarm has been triggered. Thus, the example method **500** may represent a continuous control method that, in some instances, may be a real-time control method. Consequently, the implementations of the methods described herein may be implemented into a control system that continuously intakes systemic blood pressure and infusion pressure as inputs and determine whether an alarm is to be triggered.

In some implementations, a medical device incorporating one or more of the features described herein, such as medical device **110**, may include a feature that automatically adjusts the infusion pressure (such as by increasing the rate at which material is aspirated from the eye, the rate at which material is infused into the eye, or both) in the event the infusion pressure increases above or decreases below a selected value or, for example, if the rate of change of the infusion pressure leads to or is likely to an infusion pressure above critical closing pressure.

It should be understood that, although many aspects have been described herein, some implementations may include all of the features, while others may include some features while omitting others. That is, various implementations may include one, some, or all of the features described herein without departing from the scope of the disclosure. Further, additional features not described herein may also be included in the various implementations described herein without departing from the scope of the disclosure.

A number of implementations have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the disclosure. Accordingly, other implementations are within the scope of the following claims.

What is claimed is:

1. A system for controlling infusion pressure during an intraocular surgical procedure, the system comprising:

a data receival unit that receives systemic blood pressure and infusion pressure of a fluid infused into an eye;

a computational unit that is coupled to the data receival unit and that determines an estimated retinal artery blood pressure based on the received systemic blood pressure and that determines an estimated critical closing pressure based on the estimated retinal artery blood pressure; and

a logic unit that is coupled to the computational unit and that compares the received infusion pressure with the estimated critical closure pressure and that triggers an alarm when the infusion pressure reaches a selected pressure relative to the estimated critical closing pressure.

2. The system of claim **1** wherein the systemic blood pressure comprises at least one of brachial artery blood pressure or radial artery blood pressure.

3. The system of claim **1**, wherein the computational unit adapted converts the systemic blood pressure into the estimated retinal artery blood pressure using an ophthalmodynamometry offset.

4. The system of claim **1**, wherein the alarm comprises at least one of a visual or audible alarm.

5. A system, comprising:

memory that stores at least one of systemic blood pressure data, estimated central retinal artery blood pressure data, infusion pressure data of a fluid infused into an eye, and estimated critical closing pressure data; and

one or more processors coupled to the memory, the one or more processors receives an infusion pressure of a patient's eye; determines an estimate of a patient's central retinal artery blood pressure; and determines an estimated critical closing pressure of a central retinal artery of the eye based on the estimated central retinal artery blood pressure.

6. The system of claim **5**, wherein the one or more processors receives a patient's systemic blood pressure and converts the systemic blood pressure into the estimated central retinal artery blood pressure.

7. The system of claim **6**, wherein the one or more processors converts the systemic blood pressure into the estimated central retinal artery blood pressure with an ophthalmodynamometry offset.

8. The system of claim **5** wherein the one or more processors is triggers an alarm when the infusion pressure reaches a selected pressure relative to the estimated critical closing pressure.

9. The system of claim **8**, wherein the alarm comprises a visual alarm or an audible alarm.

10. The system of claim **5**, wherein the patient's systemic blood pressure comprises the patient's brachial artery blood pressure or radial artery blood pressure.

11. The system of claim **5**, wherein the one or more processors is automatically adjusts infusion pressure when the infusion pressure is at a selected value relative to the estimated critical closing pressure.

12. The system of claim **11**, wherein the one or more processors automatically adjusts infusion pressure when the infusion pressure is at a selected value relative to the estimated critical closing pressure by automatically reducing infusion pressure when the infusion pressure is equal to or greater than the selected pressure and wherein the selected pressure is the estimated critical closing pressure.

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